Assimilation of SMOS Soil Moisture Retrievals in the Land Information System

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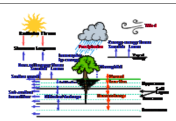
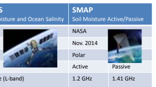
Abstract

Soil moisture is a crucial variable for weather prediction because of its influence on evaporation. It is of critical importance for drought and flood monitoring and prediction and for public health applications. The NASA Short-term Prediction Research and Transition Center (SPoRT) has implemented a new module in the NASA Land Information System (LIS) to assimilate observations from the ESA's Soil Moisture and Ocean Salinity (SMOS) satellite. SMOS Level 2 retrievals from the Microwave Imaging Radiometer using Aperture Synthesis (MIRAS) instrument are assimilated into the Noah LSM within LIS via an Ensemble Kalman Filter. The retrievals have a target volumetric accuracy of 4% at a resolution of 35-50 km. Parallel runs with and without SMOS assimilation are performed with precipitation forcing from intentionally degraded observations, and then validated against a model run using the best available precipitation data, as well as against selected station observations. The goal is to demonstrate how SMOS data assimilation can improve modeled soil states in the absence of dense rain gauge and radar networks.

Description of LIS



Description of SMOS & comparison to SMAP



Name	SMOS Soil Moisture and Ocean Salinity	SMAP Soil Moisture Active/Passive	
Agency	ESA	NASA	
Launch	2009	Nov. 2014	
Orbit	Polar	Polar	
Sensor Type	Passive	Active	Passive
Frequency	1.4 GHz (L-band)	1.2 GHz	1.41 GHz
Resolution	35-50 km	>=1-3 km	36 km
Accuracy	4 cm^3/cm^3	6 cm^3/cm^3	4 cm^3/cm^3

Applications

- **SPoRT produces real-time LIS soil moisture products for situational awareness and local numerical weather prediction over CONUS, Mesoamerica, and East Africa**
- **Currently interact/collaborate with operational partners on evaluation of soil moisture products**
  - **Drought/fire**
  - **Extreme heat**
  - **Convective initiation**
  - **Flood and water borne diseases**
- **Initial efforts to assimilate L2 soil moisture observations from SMOS (as a precursor for SMAP) have been successful**
- **Active/passive blended product from SMAP will be assimilated similarly and higher spatial resolution should improve on local-scale processes**

Description of Ensemble Kalman Filter

We assimilate AMSR-E soil moisture observations using an Ensemble Kalman Filter (EnKF) within LIS. Kalman filtering is a data assimilation method that combines a forecast (background) with observations to generate an improved estimate of a model variable. A Kalman Filter calculates an optimal weighting between the background and the observation. The EnKF uses the spread of the ensemble to represent the forecast error covariance. We used an ensemble with 16 members generated using perturbations of 3 forcing variables (incident longwave and shortwave radiation, and rainfall), 4 state variables (4 layers of soil moisture), and 1 observation variable (SMOS soil moisture).

Implementation of SMOS assimilation in LIS

- Read ECMWF Level 2 Soil Moisture User Data Product (SMUDP) files
- Read all orbits that fall in the time window (currently +/-3 hours) then exclude data outside the time window or the geographic region.
- QC for RFI, frozen soil, snowcover, falling precipitation, heavy vegetation, and data quality flags
- Use ESMF interface in LIS to assign observations to grid points.
- Use LIS Ensemble Kalman Filter to produce model state updates.

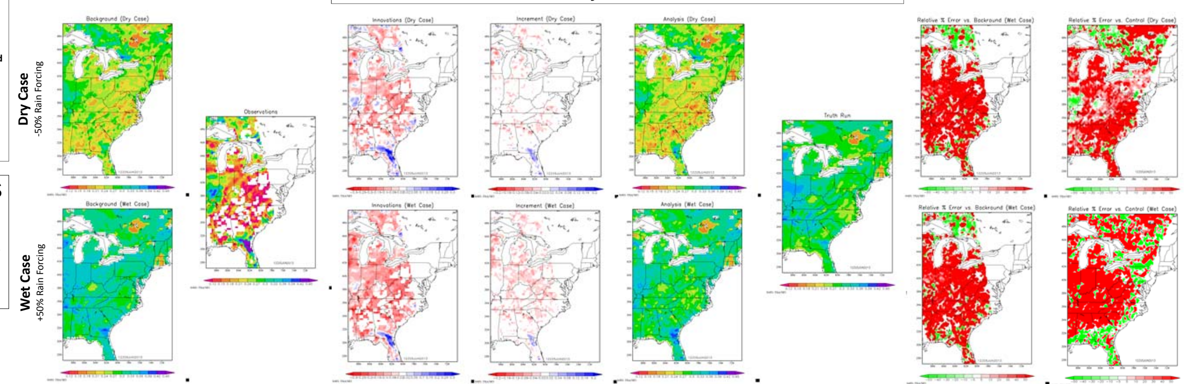
Experiment Setup

Experiment Name	Rain Forcing	Configuration	Purpose
Dry DA	0.5*GDAS	EnKF	Experiment 1
Dry Control	0.5*GDAS	Open Loop	Control 1
Wet DA	1.5*GDAS	EnKF	Experiment 2
Wet Control	1.5*GDAS	Open Loop	Control 2
"Truth" Run	GDAS	Single run	Validation

- 16 member ensembles.
- Spinup period of 8 months with state and forcing perturbations applied to generate ensemble spread.
- "Dry" and "Wet" runs with ±50% GDAS rain forcing are run in EnKF and open loop configurations to test the impact of SMOS soil moisture data assimilation on a known imperfect case as a proof of concept.
- Open loop runs are identical to EnKF runs with no data assimilated.
- Runs are validated against the run with the "correct" GDAS rain forcing.
- The EnKF runs assimilated data at 00Z and 12Z on 5 Jun 2013.

Model Configuration	
LIS Version	6.2
Land Surface Model	Noah 3.2
Domain	Eastern North America 80x92 (25 km)
Meteorological Forcing	GDAS
Model timestep	30 minutes
Data assimilation timestep	6 hours (effectively 12 hours due to data availability)

Preliminary Model Results



Background
Model surface soil moisture (cm^3/cm^3) at 12Z 5 Jun 2013 before assimilation step. There was one prior data assimilation step at 00Z.

Observations
SMOS Level 2 retrieved surface soil moisture product (cm^3/cm^3) at ~12Z 5 Jun 2013.

Innovations
Observations minus background.

Increments
Analysis minus background.

Analysis
New model field after assimilation step.

"Truth"
Model run with actual GDAS rain forcing, used for verification.

Relative Error (vs. background)

$$\left(\left|\frac{Analysis-Truth}{Background-Truth}\right|-1\right)*100$$

This is the percentage change in model error (defined as difference from "truth" run) relative to background, showing the impact of a single assimilation cycle.

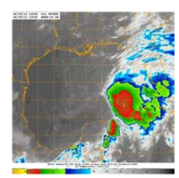
Relative Error (vs. background)

$$\left(\left|\frac{Analysis-Truth}{Control-Truth}\right|-1\right)*100$$

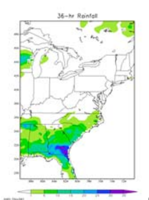
Same as previous column, but relative to control run. This shows the impact of two assimilation cycles.

Case Study

- Tropical Cyclone Andrea in June 2013
- Before landfall, precipitation in Florida and Georgia associated with outlying rain bands



GOES IR image. Courtesy of Naval Research Laboratory, Monterey, CA.



36-hr. antecedent precipitation from GDAS forcing data.

Discussion

- This is a first test of SMOS assimilation so many shortcomings still need to be addressed.
- Model "truth" (based on GDAS forcing and model physics) has errors which are not accounted for in this validation.
- There is a large dry bias in the observations (relative to the model background)
- Innovations are overall negative, even in the dry case, but there is a postive signal in the area of northern Florida/southern Georgia where precipitation occurred.
- Analysis increments have the same sign as innovations, as expected.
- Our relative error metric, hampered by model-observation bias, shows increasing error due to the analysis in most locations (red areas). However the total area with error reduction (green area) grows with repeated data assimilation cycles.

Future Improvements

- Apply a bias correction using the cumulative distribution function (CDF) adjustment of Reichle (???), possibly making it landcover-dependent (Blankenship and Crosson 201X)
- Test assimilation in a cycling run over an extended period of time
- Test in less-vegetated regions such as the Great Plains or tundra areas
- Optimize the perturbations to achieve a spread that is representative of the estimated model error.
- Determine the optimal observation uncertainty
- Perform validation against in situ soil moisture network observations.
- Implement with SMAP test data available to SMAP Early Adopters

Acknowledgements

- **Work is supported by Tsengdar Lee of the NASA Science Mission Directorate through SPoRT**
- **Would like to thank Susan Moran, Vanessa Escobar, and Molly Brown for including us as SMAP Early Adopters**

References

Aumann, H.H. et al., 2003: AIRS/AMSU/HSB on the Aqua mission: Design, science objectives, data prodcucts, and processing systems. IEEE Trans. Geoscience and Rem. Sens., 41, 2: 253-264.

Ralph, F.M. et al., 2011: Research aircraft observations of water vapor transport in atmospheric rivers and evaluation of reanalysis products. American Geophysical Union Fall Meeting 2011, A11A-046.

Reichle?

Sujay LIS

Blankenship and Crosson

See also…

- **Details on SPoRT's real-time LIS and expected use of SMAP data** can be found in
  - **Zavodsky, B. T., J. L. Case, C. B. Blankenship, W. L. Crosson, K. D. White, 2013: Application of next-generation satellite data to a high-resolution, real-time land surface model, Earthzine, J. Kart, editor, Institute of Electrical and Electronics Engineers [Available online at http://www.earthzine.org/2013/04/10/application-of-next-generation-satellite-data-to-a-high-resolution-real-time-land-surface-model/.]**

At this meeting:

- **Case (26th Conference on WAF/NWP; P162; Tues. Feb. 4)**
- **Case et al. (26th Conference on WAF/NWP; J9.4; Wed. Feb 5 @ 2:15 P.M.)**